2. CARBON CYCLE

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2.1. OVERVIEW

The goal of the Carbon Cycle Greenhouse Gases group (CCGG) is to improve the understanding of the factors that determine the atmospheric burdens of major trace gases influencing the Earth's climate, in particular CO_2, CH_4, and CO. Since 1997 N_2O and SF_6 have also been measured. The anthropogenic impact on each of these species is large, but natural cycles are involved as well, except for SF_6. The continuing international climate change negotiations highlight the fact that the world has tentatively started to take steps to control the steadily increasing climate forcing by anthropogenic greenhouse gases. Two of the requirements for effective policies are a reliable method to track the atmospheric changes of each of these gases and a quantitative understanding of what controls the atmospheric concentrations.

The main tool for studying the global budgets of the trace gases is the measurement of atmospheric spatial concentration patterns and their changes over time. Two methods have been employed from the start of the Geophysical Monitoring for Climatic Change program, the forerunner of CMDL: continuous measurements are made in remote clean-air locations, namely the four CMDL observatories; and weekly pairs of discrete flask samples are obtained, also at remote clean-air locations, and analyzed in Boulder. Initially the samples were analyzed only for CO_2, but gradually more species have been added (Table 2.1). The isotopic ratio measurements are being carried out at the Institute for Arctic and Alpine Research (INSTAAR) of the University of Colorado (CU), in close cooperation with CCGG. Anomalous ^{17}O enrichments were measured in some of the flasks by scientists at the University of California at San Diego. A California Institute of Technology scientist started to measure D/H of H_2 in a small subset of flasks in fall 2001. The global air samples provide a unique resource for narrowing uncertainties of greenhouse gas budgets as well as other atmospheric problems. CCGG continues to investigate the feasibility of additional measurements. CCGG also collaborates with a scientist from Kyrgyzstan in a project of the International Science and Technology Center, Moscow, comparing spectroscopic absorption measurements of the total column abundances of CO_2 and other species to the CCGG network data.

Information on sources and sinks of the trace gases is obtained from their rates of change and from their spatial distributions. The quantitative link is provided by numerical models of atmospheric transport, operating in both two and three dimensions. The method used is to work "backward" from observed concentrations to the sources causing them, and therefore it is in the class of so-called inverse problems. The greatest limitation is sparseness of data, especially in regions close to important sources and sinks. Therefore the spatial coverage of the cooperative air sampling network has been gradually expanded. Isotopic analyses have been added because different sources/sinks may be characterized by different isotopic "signatures."

TABLE 2.1. Species Analyzed in Samples of the Global Cooperative Air Sampling Network

Species	Start Date	Method*	Precision (1σ)	Collaborators
CO_2	1976	NDIR	0.05 ppm (0.02%)	
CH_4	1983	GC/FID	<1 ppb (0.07%)	
CO	1988	GC/HgO	0.5 ppb (0.5-1%)	
H_2	1988	GC/HgO	2 ppb (0.4%)	
CO_2, ^{13}C	1990	IRMS	0.01‰	CU/INSTAAR
CO_2, ^{18}O	1990	IRMS	0.03‰	CU/INSTAAR
N_2O	1996	GC/ECD	0.2 ppb (0.07%)	HATS group
SF_6	1996	GC/ECD	0.03 ppb (1%)	HATS group
CO_2, ^{17}O	1997	IRMS	0.03‰	UC San Diego
CH_4, ^{13}C	1998	GC/IRMS	0.06‰	CU/INSTAAR

*NDIR, non-dispersive infrared analyzer; GC, gas chromatograph; FID, flame ionization detector; IRMS, isotope ratio mass spectrometer; ECD, electron capture detector.

To overcome the limitation of having only measurements from the remote marine boundary layer, two new approaches were initiated. The first is to continuously measure a number of chemical species and atmospheric physical parameters at different heights on very tall towers. Mole fractions (also called mixing ratios) in the continental boundary layer are highly variable, making them more difficult to interpret and requiring much more auxiliary data than the traditional marine air samples. The second new approach is to obtain discrete air samples from low-cost airplanes in automated fashion from the boundary layer up to about 8-km altitude. These samples are then sent back to the laboratory in Boulder for analysis. It is hoped that the combination of continuous CO_2 and flask sampling can be greatly expanded on aircraft, especially over North America, to provide significant regional-scale constraints on the budgets of the gases measured.

Because the global coverage of CMDL's sampling network is unmatched, it plays an active role in bringing together the measurements from many different laboratories around the world. Toward this end, measurements of standard reference gases as well as actual field samples are being compared. For CO_2 and CO, CMDL provides cali-

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brated reference gas mixtures under the auspices of the World Meteorological Organization (WMO). CMDL assembles a common global database for CO_2, called GLOBALVIEW-CO_2, which is currently based on the measurements from laboratories in 13 countries, and in which an attempt is made to avoid significant calibration or methodological inconsistencies. Its intended use is for three-dimensional (inverse) modeling. Its first release took place in 1996, and it has been updated once a year since then, around August (http://www.cmdl.noaa.gov/ccgg/global-view/co2/index.html). A similar database was assembled for methane, GLOBALVIEW-CH_4. The first release occurred in 1999, and a second release took place in December 2001 [*GLOBALVIEW-CH_4*, 2001].

Full individual data records and monthly means can be obtained for each species for each site from the CMDL World Wide Web page (http://www.cmdl.noaa.gov); from the ftp file server's "pub" directory (ftp.cmdl.noaa.gov); from the WMO World Data Center for Greenhouse Gases in Tokyo, Japan; and from the Carbon Dioxide Information Analysis Center in Oak Ridge, Tennessee.